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A POSSIBLE IMPACT OF THE JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM (JTIDS) ON ASTRO-DABS

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16 Abstract

The development of the ASTRO-DABS concept to date has assumed availability of the Aeronautical L-band. Due to its increased usage, however, consideration is being given to operating ASTRO-DABS in the TACAN band, a portion of the frequency spectrum which is also being considered for use by the military program JTIDS (Joint Tactical Information Distribution System). Because of JTIDS operating characteristics, there is concern that ASTRO-DABS performance may be impaired. The present report presents a preliminary analysis, and corresponding numerical results, as to the impact of JTIDS on ASTRO-DABS. Areas for possible future investigation, and means for more detailed analyses, are also included. The preliminary indications, however, are that coexistence of ASTRO-DABS and JTIDS in the same frequency band would severely degrade the downlink (satellite-to-aircraft) performance of ASTRO-DABS.

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CONCLUSIONS

Preliminary findings indicate that colocation of ASTRO-DABS and JTIDS in the TACAN band may produce severe degradation of the downlink data detection portion (satellite-to-aircraft) of ASTRO-DABS. Uplink performance, on the other hand, does not appear to be degraded significantly, but further investigation does appear warranted. The impact of JTIDS was further found to be negligible on synchronization and range estimation for both uplink and downlink if a hard limiter is included at the front end of the ASTRO-DABS receiver.

Based on several assumptions relating to JTIDS signal structure and transmission characteristics the following was found:

1. For a 10 mile separation between JTIDS emitter and ASTRO-DABS receiver, ASTRO-DABS downlink messages are obstructed more than 17% of the time.

2. A separation exceeding 100 miles is required to reduce the above percentage to 0.1%.

3. Uplink data detection probability of error is increased by less than an order of magnitude as compared to the corresponding result in the absence of interference.

Additional implications of degraded data detection performance are:

1. Possible increase in Acquisition mode garble.

2. Retransmission of data in Tracking mode.

These two factors may lead to a reduction in ASTRO-DABS capacity.

The preliminary findings thus indicate that coexistence of JTIDS and ASTRO-DABS in the same frequency band may not be possible. Since several assumptions and approximations were made, however, any future investigation should characterize JTIDS as to its statistics, distribution of emitters, duty cycles, etc., to ensure the accuracy of the current findings.

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1. INTRODUCTION

The availability of sufficient frequency spectrum in the Aeronautical L-band (1540 MHz - 1660 MHz) has been assumed in development of the ASTRO-DABS concept to date. However, significantly increased usage of this frequency band is expected (e.g., by GPS, MARISAT, and AEROSAT). An alternate choice for operating ASTRO-DABS is the TACAN band (960 MHz - 1215 MHz), over which the FAA has been given first preference. Currently, the military is also considering employment of the TACAN band for the Joint Tactical Information Distribution System (JTIDS). A description of proposed usage is presented in Figure 1-1.* Since JTIDS has been designed to perform satisfactorily in the presence of jamming, the co-presence of ASTRO-DABS does not affect it. Because of JTIDS characteristics, however, the performance of ASTRO-DABS may be impaired.

The present report presents a preliminary analysis of JTIDS effects on ASTRO-DABS, together with the associated findings. Section 2 describes the potential areas of concern, Section 3 provides a description of the pertinent aspects of JTIDS, and Section 4 contains the analysis and calculations. The report concludes with Section 5 which contains a discussion of results and areas for possible further investigation.

* The frequency spectrum requirements of JTIDS are described further in Section 3.

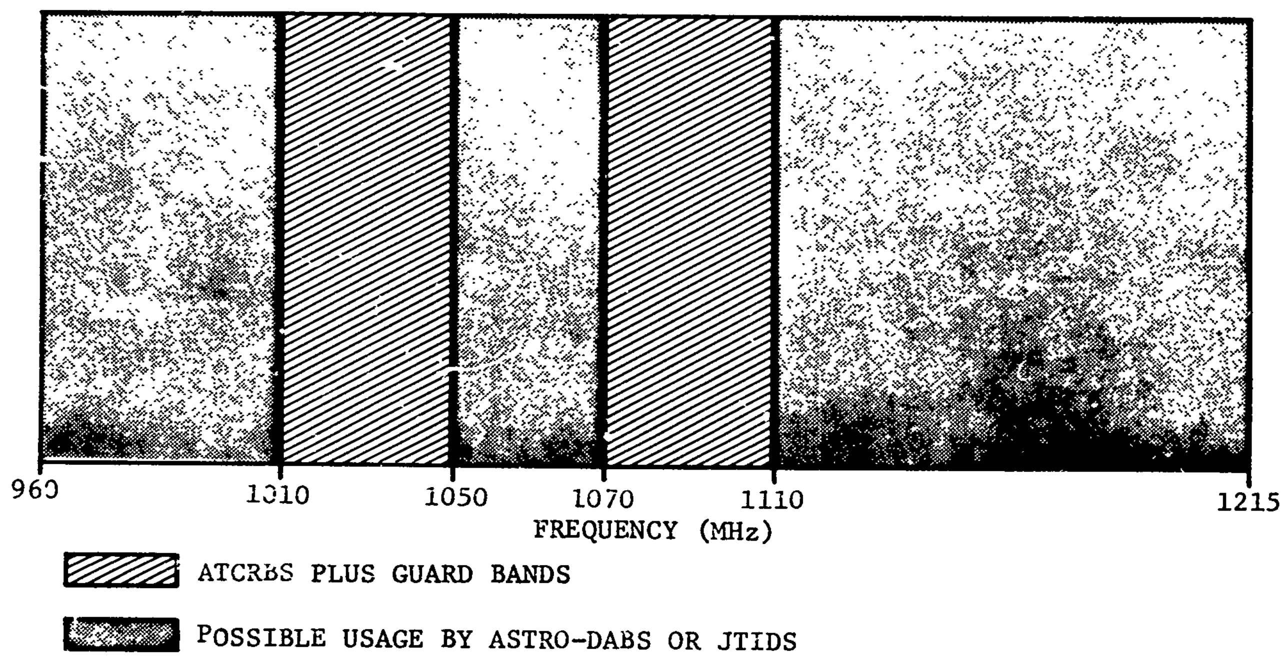

FIGURE 1-1
DESCRIPTION OF TACAN BAND

2. AREAS OF CONSIDERATION

While ASTRO-DABS consists of several modes of operation (e.g., Tracking, Acquisition, Navigation) the system aspects to be investigated may be separated into the portions: a) Downlink (Satellite-to-Aircraft) transmissions, and b) Uplink (Aircraft-to-Satellite) transmissions. The specific areas of consideration are listed in Table 2-1 and briefly described in the following:

2.1 Downlink Transmissions

Of primary importance in all downlink transmissions is the achievement of synchronization from the 60 μs sync burst that is considered in each message set preamble. The sync burst is followed by 10 data bits which specify the mode of operation (e.g., Tracking) a gap time of 75 μs, and finally the specific mode information. Downlink transmissions also contain messages of varying lengths. Each message consists of a string of 1.5 μs data bits. Examples of message lengths are: 10 bits for mode specification, 3 bits for address group specification during Acquisition, and 31, 56, or 84 bits for address plus PWI, IPC, or ATC messages during Tracking. Finally, Navigation messages consist of both data and timing transmissions. The data portion provides information such as ionospheric excess delay corrections, while the timing portion consists of several 180 μs coded timing pulses (120 bits). The pulses are generated by each one of the visible satellites and the aircraft derives time-of-arrival (TOA) differences from which to calculate position.

2.2 Uplink Transmissions

Aircraft replies to Tracking and Acquisition mode interrogations are of interest here. The Acquisition response consists of a sync burst (67.5 μs) followed by aircraft address bits (97.5 μs). The Tracking mode response is comprised of a 33 μs ranging sequence,

TABLE 2-1

ASTRO-DABS DOWNLINK AND UPLINK CHARACTERISTICS

DOWNLINK (SATELLITE-TO-AIRCRAFT)

a) Preamble Synchronization (60 μs) -

provides synchronization for detection of data bits that follow

b) Data Detection (1.5 μs/data bit) -

messages contain mode, address, ionospheric data, IPC data, etc.

c) Navigation (180 μs) -

position location obtained via time-of-arrival (TOA) estimation

UPLINK (AIRCRAFT-TO-SATELLITE)

a) TOA (Range) Estimation (33 μs) -

provides 3-D surveillance capability

b) Acquisition Mode Synchronization (67.5 μs) -

provides synchronization for detection of aircraft address bits that follow

c) Data Detection (1.5 μs/data bit) -

confirms aircraft reception of data, provides aircraft address information, or provides information originated by aircraft

from which synchronization, TOA and, hence, range information is derived by the ground facilities. This is followed by a surveillance message, that is either 9 μs, 51 μs, or 93 μs in duration, which contains the data bits received by the aircraft during the interrogation process. An incorrect detection of any data bit would necessitate a retransmission to that aircraft at the next cycle, some 4-5 seconds later.

3. DESCRIPTION OF JTIDS

JTIDS messages are transmitted in blocks of 7.8 ms and consist of a sync burst, followed by the pertinent data, and finally a guard or gap time. In accordance with JTIDS specifications, the average gap time is approximately 3.8 ms or roughtly 48% of each 7.8 ms message block.

JTIDS chip durations are nominally 0.2 μs, which corresponds to a chip bandwidth of 10 MHz. During each 7.8 ms transmission period information is conveyed by 6.4 μs message blocks, which are encoded via pseudo-random noise techniques with successive message blocks separated by 6.6 μs; the modulation scheme is Continuous Phase Shift Modulation (CPSM). To assure additional security in the transmission process frequency hopping is also employed. Fifty-one frequencies are employed in the TACAN band with a 3 MHz separation between frequencies except for 20 MHz guard bands around tha ATCRBS frequencies 1030 MHz and 1090 MHz (Figure 1-1). With respect to ASTRO-DABS, all JTIDS frequencies occur with equal probability at all times. JTIDS characteristics are summarized in Table 3-1.

TABLE 3-1

JTIDS CHARACTERISTICS

Signal Power (Normal Mode)	200 Watts*
Chip Duration	0.2 μs
Chip Bandwidth	10 MHz
Message Block	6.4 μs
Gap Time Between Message Blocks	6.6 μs
Total Message Duration	7.8 ms
Average Gap Time Between Messages	4 ms
Number of Frequencies	51
Frequency Separation	3 MHz

* JTIDS can operate with 1KW transmissions.

4. ANALYSIS AND CALCULATIONS

4.1 Preliminaries

For this preliminary analysis, four primary assumptions are made:

1. One JTIDS data bus is operating at full capacity so that transmissions occur in each 7.8 ms block. In accordance with Section 3, this implies that actual JTIDS signals* are present 48% of the time.

2. The JTIDS signal acts as a white noise. This is due to the JTIDS signal power spectrum being essentially flat over a 7 MHz bandwidth, which is larger than that of ASTRO-DABS (5.33 MHz). The corresponding power spectral density is then obtained by dividing the JTIDS power by 7×10^6.

3. There are three adjacent frequency bands that can overlap a given ASTRO-DABS band. Because the JTIDS frequency separation is 3.0 MHz, with its nominal bandwidth almost twice that of ASTRO-DABS, it follows that the upper and lower JTIDS bands, relative to one which is centered on the ASTRO-DABS frequency, will also overlap ASTRO-DABS. These sidebands are also assumed to appear as white noise to ASTRO-DABS, although this is not precisely the case.

4. The average distance between a JTIDS emitter and an ASTRO-DABS aircraft is 10 nmi. This 10 mile average figure was chosen arbitrarily but can be used as a basis for comparison. Furthermore, this separation distance would not be unreasonable if JTIDS aircraft are operating in the vicinity of airports.

* The JTIDS signal here means a 6.4 μs message block and a 6.6 μs gap time, or 13 μs total.

In all but one of the calculations, these assumptions are sufficient. In one case, however, the additional assumption that the JTIDS signal is Gaussian is made. Although this is not actually the case, it is felt that an appropriate feel for what may be expected is obtained via this assumption. It should also be noted, however, that a more exact analysis does appear possible. The framework for such an analysis is presented in Appendix A.

In order to obtain numerical results on ASTRO-DABS performance degradation, it is necessary to obtain expressions for probability of message error and for the timing error standard deviation which incorporates JTIDS effects. This is accomplished in the following subsections.

4.1.1 Probability of Message Error

An expression for probability of message error must include the effects of interference through a specification of its strength, statistical characterization, and probability of frequency overlap with ASTRO-DABS. A general expression for the probability of message error, P_M, may be written as:

$$P_M = \Pr\{\text{message error}|\text{JTIDS overlap}\}\Pr\{\text{JTIDS overlap}\} + \Pr\{\text{message error}|\text{no JTIDS overlap}\}\Pr\{\text{no JTIDS overlap}\} \tag{4-1}$$

Under conditions of interest in this report, the latter term in (4-1) will generally be insignificant* and will, therefore, be neglected in the following. Equation (4-1) then reduces to:

$$P_M \approx P_J \cdot P_F \tag{4-2}$$

*For the largest possible message of 84 data bits plus 10 mode bits, this error probability is less than 10^{-4}.

where

$$P_J \triangleq \Pr \{\text{message error} | \text{JTIDS overlap}\} \tag{4-3}$$

$$P_F \triangleq \Pr \{\text{JTIDS overlap}\} \tag{4-4}$$

In accordance with the above assumptions, the probability, P_F, in a time interval, T, may be determined. Denoting by m the integer part of T/13, one gets:

$$(.48)\left[1 - (1 - \frac{3}{51})^{m+1}\right] \geq P_F \geq (.48)\left[1 - (1 - \frac{3}{51})^{m}\right] \tag{4-5}$$

The factor 0.43 represents the fraction of time JTIDS signals are present, and 3/51 the probability of a single frequency overlap (i.e., three potential JTIDS frequencies out of a possible 51).

To determine P_F, it is assumed that ASTRO-DABS messages are at least 13 μs long and that a single bit error implies a message error. Now, if the JTIDS signal frequency overlaps ASTRO-DABS, at least three of the latter's data bits are completely interfered with. Denoting by P_e the probability of a single bit error, conditioned on interference being present, one obtains,

$$P_J \geq 1 - (1 - P_e)^3 \tag{4-6}$$

The overall probability of message error, P_M, is now obtained by placing (4-5) and (4-6) into (4-2). A lower bound results and is given by

$$P_M \geq (.48)\left[1 - (1 - \frac{3}{51})^{m}\right]\left[1 - (1 - P_e)^3\right] \tag{4-7}$$

Equation (4-7) serves as a useful criterion for situations in which the probability of error is relatively high. For later calculations, it will also be desirable to have an approximate expression for P_M which may be applied to low probability of error situations. This may be accomplished by first observing that the probability of more than one JTIDS overlap, over a given ASTRO-DABS message duration, is generally much less than the probability of exactly one overlap. Thus as a first approximation, it is only necessary to determine the joint probability of a message error and exactly one JTIDS overlap. If one further assumes interference on four ASTRO-DABS bits, the resulting probability of message error, $\hat{P}_M$, becomes,

$$\hat{P}_M \approx (.48)\ (m) \left(\frac{3}{51}\right) \left(1 - \frac{3}{51}\right)^{m-1} \left[1 - (1 - P_e)^4\right] \qquad (4\text{-}8)$$

To complete the evaluations of (4-2) and (4-8), one must determine P_e, which, in turn, requires a determination of the JTIDS signal amplitude probability distribution. Appendix A considers this problem exactly. For the present purposes, however, the JTIDS signal is considered to be an additive White Gaussian noise. The probability of bit error P_e, is then given by

$$P_e = \frac{1}{2} e^{-E_b/N_o} \qquad (4\text{-}9)^*$$

where E_b/N_o is the bit signal-to-noise ratio (SNR) and N_o incorporates thermal noise and JTIDS effects.

* As discussed in [3], under suitable operating conditions this result is valid whether or not a hard-limiter is present at the receiver front end. Although more investigation is required, it is here assumed that a limiter presence does not enhance or degrade performance.

4.1.2 Timing Error Standard Deviation

To minimize the effects of JTIDS interference on synchronization and TOA estimation accuracies, it has been proposed [2] that a hard-limiter be included in the front end of each ASTRO-DABS receiver. Its presence is expected to reduce the impact of short interference bursts while, hopefully, only slightly degrading the performance of ASTRO-DABS when interference is absent.

To calculate the timing error standard deviation, σ_ε, let a given synchronization or ranging sequence contain N bits, with N_1 bits having one SNR and $N_2 = N - N_1$, bits having another. σ_ε is then given by,

$$\sigma_\varepsilon \approx \tau \frac{\sqrt{N_1 \sigma_1^2 + N_2 \sigma_2^2}}{N_1 m_1' + N_2 m_2'} \qquad (4\text{-}10)$$

where τ is the ASTRO-DABS chip duration. σ_i^2 and m_i' are given by somewhat complex expressions [3] but may be characterized as follows. The TOA estimate is found by searching for the peak of the estimator output. $N_i m_i'$ then is the derivative of the mean, and $N_i\ \sigma_i^2$ the variance, of the estimator output derivative. It should be pointed out that (4-10) does not depend on the JTIDS signal amplitude probability distribution and is valid only if $\sigma_\varepsilon << \tau$.

The advantage of employing hard-limiting can be explained with the aid to (4-10). To do this, let N_1 be the number of bits that are interfered with. When no limiter is present the denominator of (4-10) is independent of interference effects while the numerator may grow without bound as the SNR over the N_1 bits decreases; this would be the case regardless of how high the SNR is over the remaining N_2 bits. When a limiter is present, however, both the

numerator and denominator of (4-10) are functions of SNR. Specifically, $N_1 m_1'$ decreases as its SNR increases while $N_1 \sigma_1^2$ can increase only up to a fixed limit. Therefore, if the number of interference corrupted bits is sufficiently small, the resulting degradation will also be small.

4.2 Downlink Performance

4.2.1 Description

The downlink situation is described in Figure 4-1. A Surveillance/ Data Link (SD) satellite is employed for all sychronization and data transmissions, while Surveillance/Navigation (SN) satellites are used for navigation timing pulse transmissions. For calculation purposes it is assumed that the separation between an ASTRO-DABS (A-D) aircraft (A_1) and JTIDS emitter (A_2) is 10 miles. It is further assumed, for simplicity, that the JTIDS signal acts as a white noise over the ASTRO-DABS bandwidth. Specifically, an examination of the JTIDS signal power spectrum shows it to be approximately flat over a 7 MHz bandwidth.* Thus, the corresponding spectral density is equal to the JTIDS power received at A_1 divided by its 7 MHz bandwidth.

To determine the effects of A_2 on A_1 it is first necessary to calculate the received A-D and JTIDS powers at the front end of A_1 and form the overall link SNR. This is done in two stages as shown in Tables 4-1 and 4-2. It should be noted that both SD and SN satellite antenna gain values are 3 dB lower than their aeronautical L-band equivalents [4]; this is a consequence of the lower operating frequency considered here and the satellite antenna size remaining constant. However, the path loss exactly compensates for this, leaving the result the same as for the higher frequency.

* The nominal chip bandwidth is 10 MHz, corresponding to a 0.2 μs nominal chip width.

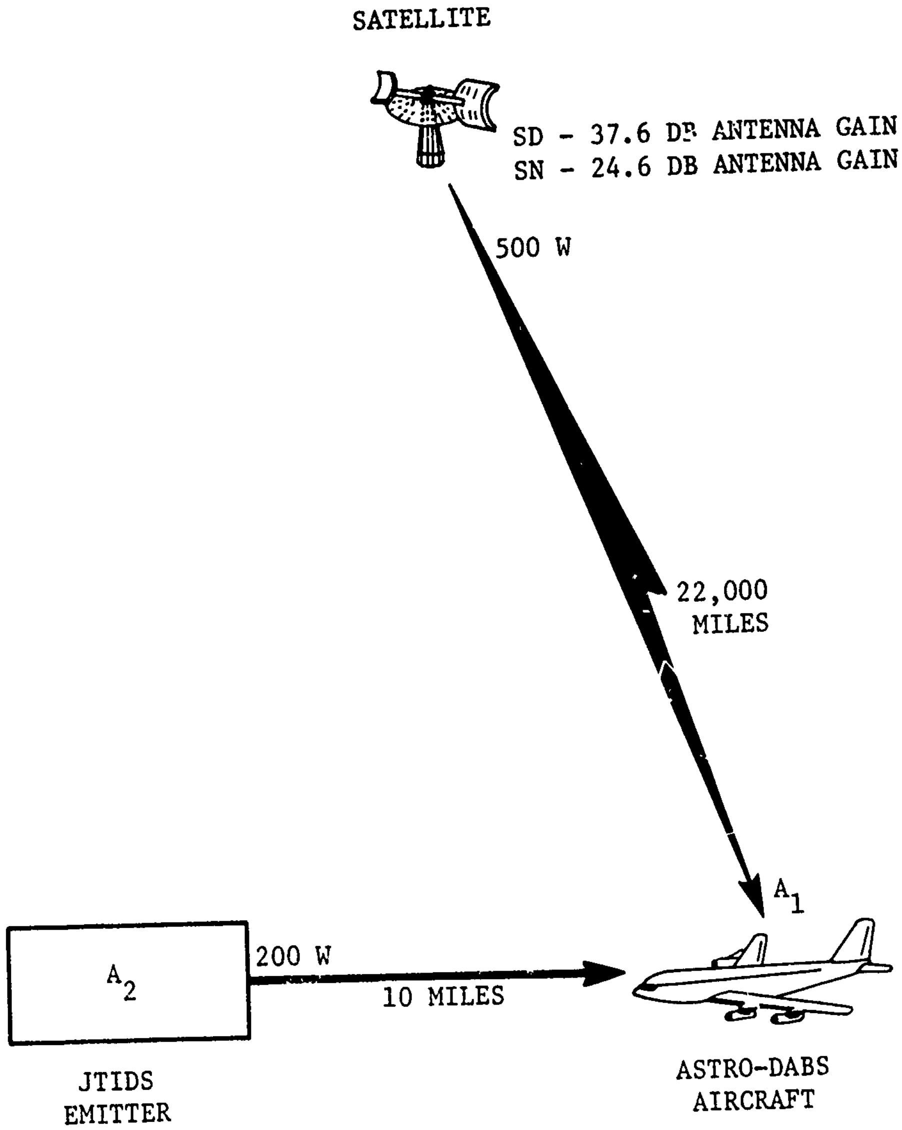

FIGURE 4-1
DESCRIPTION OF DOWNLINK SITUATION

TABLE 4-1

DOWNLINK BUDGET - POWER CALCULATIONS

	$A_2 \rightarrow A_1$	SD Sat. $\rightarrow A_1$
Transmitter Frequency (MHz)	1150	1150
Transmitted Power (dBW)	23 (200W)	27 (500W)
Antenna Gain (dB)	0	37.6*
Off Center Beam Loss (dB)	0	-2
Polarization Loss (dB)	-3	0
Path Loss (dB)	-118	-185
A_1 Antenna Gain (dB)	0	0
Received Power (dBW)	-98	-122.4

*SN satellite antenna gain = 24.6 dB

TABLE 4-2

DOWNLINK BUDGET - SNR CALCULATIONS

Received JTIDS Power (dBW)	-98
JTIDS Power Spectral Density - 7 MHz bandwidth (dBJ)	-166.5
Receiver Noise Spectral Density (dBJ)	-198
Overall Power Spectral Density -N_o (dBJ)	-166.4
Received Satellite Power (dBW)	-122.4
Bit Width - 1.5 μs (dBS)	- 58.2
Received Bit Energy - E_b (dBJ)	-180.6
Bit SNR - E_b/N_o (dB)	-14.2*

(No additional link margin is included)

*Bit SNR $\approx$ -27.2 dB when SN satellite is employed.

With the aid of these link budgets specific results may now be obtained.

4.2.2 Preamble Synchronization

The preamble sync burst is 60 μs in duration and is, therefore, composed of forty 1.5 μs bits. For a 6.4 μs JTIDS message block, then, approximately 4 ASTRO-DABS bits are overlapped in time, whenever frequency overlap occurs.* To determine the standard deviation of the synchronization timing error, σ_ε, it is necessary to employ the following values in evaluating (4-10):

$$N_1 = 4; S_1 = -14.2 \text{ dB} \approx 0.038; N_2 = 36; S_2 = 11 \text{ dB} \approx 12.6^{**} \quad (4\text{-}11)$$

where S_i denotes the SNR over N_i bits.

The result is

$$\sigma_\varepsilon \approx 7.2 \text{ ns} \quad (4\text{-}12)$$

This compares to a σ_ε value of 5.3 ns when no interference is present, and no limiter is used. Clearly, a synchronization capability has been maintained. It is interesting that syncnronization cannot be achieved if the JTIDS signal is present and no hard-limiter is employed. The advantage of receiver front end hard-limicing has thus been verified.

4.2.3 Navigation Timing

Navigation transmissions are 180 μs long and thus contain 120 1.5 μs bits. Again, (4-10) is used to determine the standard deviation of the timing (time-of-arrival) error. In this case,

$$N_1 = 4; S_1 \approx 0.002^{***}; N_2 = 116; S_2 \approx 0.74^{***} \quad (4\text{-}13)$$

* Although more than one frequency overlap can occur, with a corresponding increase in timing error, its probability is much lower than that of exactly one frequency overlap. Therefore, its effect on an overall standard deviation result would be negligible.

** γ = 11 dB is the E_b/N_o that would result without JTIDS [4].

*** Due to 13 dB lower antenna gain on SN satellite.

which leads to

$$\sigma_{\varepsilon} \simeq 16.5 \text{ ns} \tag{4-14}$$

This compares to 14.5 ns when no interference is present and no limiter is used. Again, the interference effects are insignificant.* Futhermore, analogous to the synchronization situation, the limiter presence prevents significant degradation of navigation capability.

4.2.4 Data Detection

Data streams of different durations occur during satellite-to-aircraft transmissions. Of particular interest here is the largest Tracking mode message, which consists of 10 mode bits plus a successive string of 22 address and 62 data bits. The 62 bits contain IPC data, and correct detection of all bits is imperative. The motivation for considering this specific message is thus clear.

A message error occurs if at least one of the 84 address plus data bits is detected incorrectly,** and its probability may be determined from (4-7). For the SNR data in Table 4-2 it can be observed that P_e in (4-7) is approximately 0.5. This actually is not based on any JTIDS signal distribution but is simply due to the very low bit SNR (-14.2 dB).*** Also, for the 84 bit message, m = 9. The probability of message error then is lower bounded by,

$$P_m > (.48)\left[1 - \left(1 - \frac{3}{51}\right)^9\right]\left[1 - (.5)^3\right] \approx .17 \tag{4-15}$$

* Some degradation in navigation accuracy does apparently result due to the limiter presence. This can, however, be compensated by increasing the navigation timing pulse duration accordingly.

** The probability of mode error is small compared to the remaining error probability.

*** For the Gaussian White noise case, a -14.2 dB bit SNR leads to message error, $P_e = 0.48 \simeq 0.5$.

In other words, when the separation between a JTIDS emitter and an ASTRO-DABS aircraft is 10 miles, at least 17% of all IPC messages received by that aircraft will be detected incorrectly. The unacceptability of this result is quite apparent.

4.3 Uplink Performance

The uplink situation is described in Figure 4-2. Again the JTIDS signal is assumed to act as a white noise due to its power spectrum being roughly flat over a 7 MHz bandwidth. The power and SNR link budget calculations are presented in Tables 4-3 and 4-4. Note that these link budgets include both the SD and SN satellites. In accordance with the ASTRO-DABS concept, the SD satellite is the primary receiver for data detection, while the constellation of SN satellites is more significant with respect to range estimation.

4.3.1 Range (TOA) Estimation

Uplink transmissions consist of both Acquisition and Tracking mode messages. TOA estimation is performed in both modes, but the shorter messages are found in the Tracking mode (33 μs) and are, therefore, considered here.* The parameters to be used in evaluating (4-10)** are thus,

$$N_1 = 4;\ S_1 = 3.5;\ N_2 = 18;\ S_2 = 7.5\ \text{dB} \approx 5.6 \qquad (4\text{-}16)$$

and the resulting σ_ε is

$$\sigma_\varepsilon \approx 13.0\ \text{ns} \qquad (4\text{-}17)$$

as compared to 11.0 ns without interference. It is clear that the σ_ε of (4-17) is well within the desired timing accuracy limits (10 ns - 14 ns).

* The longer messages may lead to higher probabilities of frequency overlap but the corresponding σ_ε values will be affected less by JTIDS.

** The receiver of interest here is the Satellite Control Center (SCC). Note that a hard-limiter at the front end of the SCC receiver is assumed, although this may not be necessary if JTIDS emitters are prevented from operating in the vicinity of the SCC.

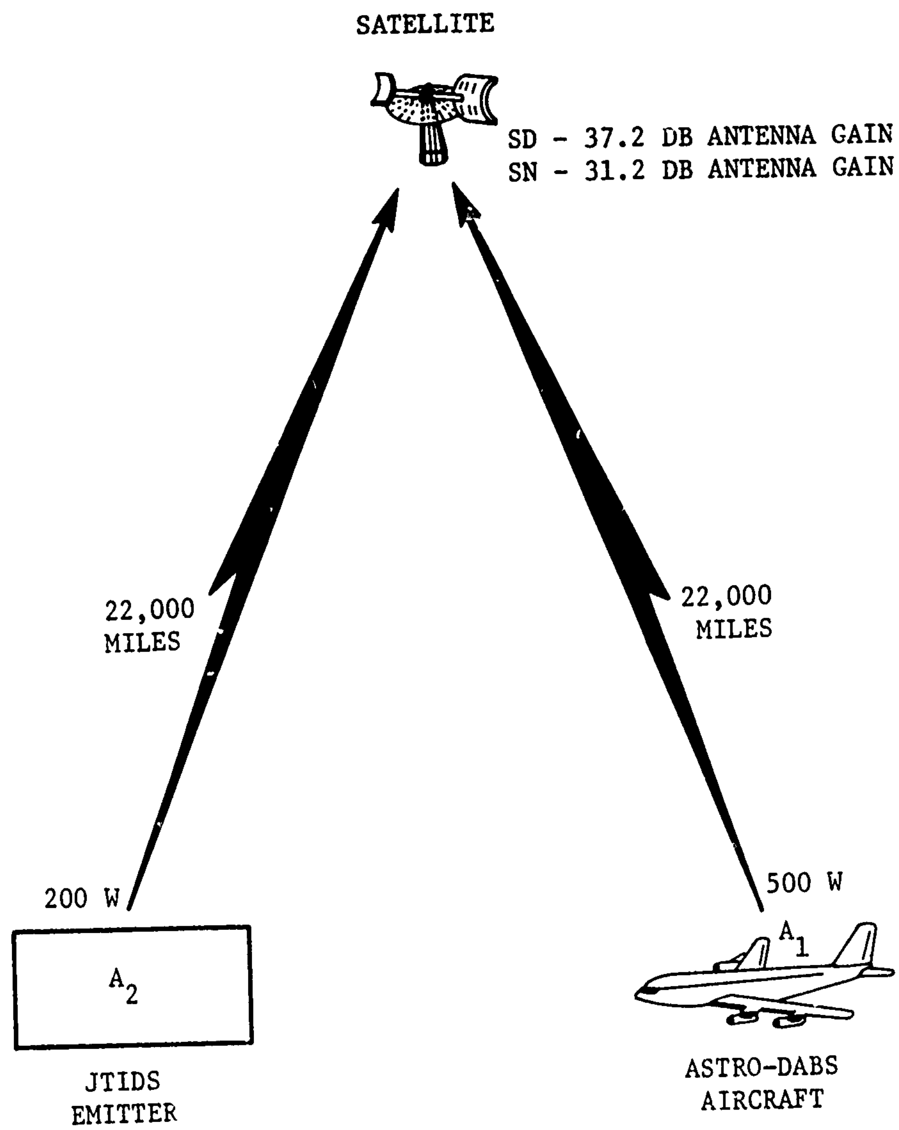

FIGURE 4-2
DESCRIPTION OF UPLINK SITUATION

TABLE 4-3

UPLINK BUDGET - POWER CALCULATIONS

	$A_1 \rightarrow SD$	$A_1 \rightarrow SN$	$A_2 \rightarrow SD$	$A_2 \rightarrow SN$
Transmitter Frequency (MHz)	1100	1100	1100	1100
Transmitted Power (dBW)	27(500W)	27(500W)	23(200W)	23(200W)
Antenna Gain (dB)	0	0	0	0
Off Center Beam Loss (dB)	-2	-3	-2	-3
Polarization Loss (dB)	0	0	-3	-3
Path Loss (dB)	-185	-185	-185	-185
Satellite Antenna Gain (dB)	37.2	31.2	37.2	31.2
Received Power (dBW)	-122.8	-129.8	-129.8	-136.8

TABLE 4-4

UPLINK BUDGET - SNR CALCULATIONS

	SD	SN
Received JTIDS Power (dBW)	-129.8	-136.8
JTIDS Power Spectral Density - 7 MHz Bandwidth (dBJ)	-198	-205
Receiver Noise Spectral Density (dBJ)	-201	-201
Overall Power Spectral Density $-N_o$ (dBJ)	-196	-199.5
Received ASTRO-DABS Power (dBW)	-122.8	-129.8
Bit Width - 1.5 μs (dBS)	- 58.2	- 58.2
Received Energy -E (dBJ)	-181	-188
Bit SNR - E/N_o (dB)	15	11.5
Additional Link Margin (dB)	6	6
Net Bit SNR (dB)	9	5.5

4.3.2 Data Detection

Messages transmitted by ASTRO-DABS aircraft consist of either address bits or Tracking mode message bits that it received during the interrogation procedure. As in subsection 4.2.4, the 62 bit Tracking mode message, which contains IPC data, is considered here.* To precisely determine the probability of bit error the statistical properties of the JTIDS signal must be more fully characterized. This characterization, together with a method for a detailed analysis, is presented in Appendix A. For present purposes, however, a feel for what may be expected is obtained by assuming the JTIDS signal to be white Gaussian noise. Based on this assumption, the overall probability of message error P_M, from (4-7), is

$$P_M \geq 6.3 \times 10^{-5} \tag{4-18}$$

where a bit SNR of 9 dB has been used. The corresponding joint probability ($\hat{P}_M$) of a message error and exactly one JTIDS overlap occurring is given by (4-8). The result is

$$\hat{P}_M \approx 10^{-4} \tag{4-19}$$

Note that these results are independent of the separation between an ASTRO-DABS aircraft and a JTIDS emitter.

Since the corresponding ASTRO-DABS result without interference is less than 6.2×10^{-5} for the 62 bit message,** it follows that the presence of JTIDS increases the probability of message error by substantially less than an order of magnitude. This is the case even if $\hat{P}_M$ is adjusted by including the ASTRO-DABS performance under no interference conditions (eq. (4-1)). However, although

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* The 22 bits that precede the 62 bits under consideration are used for TOA estimation and are therefore not employed during the data detection procedure.

** The ASTRO-DABS probability of a bit error is nominally 10^{-6} [4].

the interference effects appear minor, it must be recalled that several simplifying assumptions relating to JTIDS characteristics were used in deriving these results. Furthermore, 1 KW JTIDS are also possible. It thus, appears that some additional investigation may still be required.

5. SUMMARY

A preliminary investigation on the possible effects the Joint Tactical Information Distribution System (JTIDS) may have on the various operating modes of ASTRO-DABS, has been carried out. A situation, in which a single JTIDS data bus is operating at full capacity, was assumed. As a simplifying assumption, the JTIDS signal was considered to be a white noise over the ASTRO-DABS bandwidth. The additional assumption that the JTIDS signal is Gaussian, was made for only one of the several situations examined.

The evaluations were partitioned into the two classes: Satellite-to-Aircraft (Downlink) and Aircraft-to-Satellite (Uplink). A summary of results is presented in Tables 5-1 and 5-2, along with typical ASTRO-DABS performance in the absence of interference and absence of front end hard-limiting.

The tabulated results, which correspond to 200 Watt JTIDS transmissions, indicate that JTIDS could cause potentially severe degradation on the downlink portion of ASTRO-DABS, with uplink degradation small but still somewhat in question. The downlink observation is of primary interest and is due to the fact that critical downlink messages may be detected incorrectly, under the 10 mile separation assumption. In fact, calculations using (4-8) show that even a 0.001 probability of message error (84 bits)--the adequacy of which may be questionable--requires a downlink bit SNR of 7.6 dB, which corresponds to a separation of at least 100 miles.

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* When 1 KW JTIDS transmissions are present, both uplink and downlink data detection performances deteriorate further, although timing operations are only negligibly affected.

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TABLE 5-2
UPLINK PERFORMANCE

JTIDS transmitter power - 200 watts

Mode of Operation	ASTRO-DABS Performance: Presence of JTIDS and Front End Limiter	ASTRO-DABS Performance: Absence of Limiter and Interference
Acquisition Synchronization Timing Accuracy (1σ)	9.0 ns (Satisfactory)	7.8 ns
Time-of-Arrival Estimation Accuracy (1σ)	13.0 ns (Satisfactory)	11.0 ns
Probability of Message Error (62 bit Message)	$\approx 10^{-4}$ (Questionable)	$\leq 6.2 \times 10^{-5}$

For other message lengths and modes of operations, downlink message error probabilities differ from the one corresponding to the above situation. For example an Acquisition mode message error probability exceeds 0.035. Accordingly, careful consideration must be given to the several modes of ASTRO-DABS and how sensitive they are to system malfunctions. Specifically, if downlink data transmission is obstructed by JTIDS, examples of possibilities which present themselves are:

a) Aircraft may reply out of turn in the Acquisition mode thus increasing garble, or they may not reply at all.

b) During the Tracking mode, reinterrogations of aircraft may be necessitated more often than the nominal rate.

Both a) and b) can potentially lead to severe complications if they cause longer acquisition times and additional interrogations, since the capacity of ASTRO-DABS may be diminished. Furthermore, as noted above, separations exceeding 100 miles may be required for satisfactory interference rejection--a separation which may be difficult to guarantee.

It would appear that further investigation into the above matter is required. Such a study should include the following elements:

a) More exact analysis as outlined in Appendix A.

b) Further specification of JTIDS aircraft distribution around CONUS.

c) Further specification of overall time usage of JTIDS.

d) Additional impact of several coexisting JTIDS buses.

e) Additional impact of 1 KW JTIDS transmissions.

f) Possible remedies if interference is in fact severe (e.g., assured frequency separation).

With respect to f), it should be emphasized that methods such as error correction and employment of longer messages do not appear to be feasible alternatives since they would immediately reduce ASTRO-DABS capacity. Increased transmitter powers and antenna gains also may not plausible due to system coverage regions and cost considerations.

APPENDIX A

ELEMENTS OF DETAILED ANALYSIS WHICH INCLUDES JTIDS EFFECTS

Let the receiver pertain to either an ASTRO-DABS satellite or aircraft. In either case the received signal, at any instant of time, may be written as

$$r(t) = k\,A \cos (wt + \theta) + B \cos [wt + \Delta(t) + \phi] + n(t) \qquad \text{(A-1)}$$

where elements on the right pertain to the ASTRO-DABS signal, JTIDS signal*, and the receiver noise, respectively. Also, k denotes the polarity of the ASTRO-DABS chip being received while $\Delta(t)$ equals either $(+\,\pi t/2\hat{T})$ or $(-\,\pi t/2\hat{T})$, where $\hat{T}$ is the JTIDS chip width. Furthermore, for the data detection process, it is assumed that ASTRO-DABS chip transition times are known, while those pertaining to JTIDS are, of course, not known. Finally, θ and ϕ are independent random variables, uniformly distributed in $(-\pi, \pi)$.

The demodulation procedure is described in Figure A-1. For simplicity here all pulse waveshapes are assumed to be rectangular. The following is readily obtained from Figure A-1:

$$X_i = k_i \frac{A}{2} \cos \theta + \frac{B}{2} \int_0^T \cos [\Delta(t) + \phi]\, dt + n_{ci} \qquad \text{(A-2)}$$

$$Y_i = k_i \frac{A}{2} \sin \theta + \frac{B}{2} \int_0^T \sin [\Delta(t) + \phi]\, dt + n_{si} \qquad \text{(A-3)}$$

where T is the bit period, and n_c and n_s are independent zero mean Gaussian random variables, each with variance $N_0T/4$. Now,

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*JTIDS employs CPSM, which is a form of frequency shift keying.

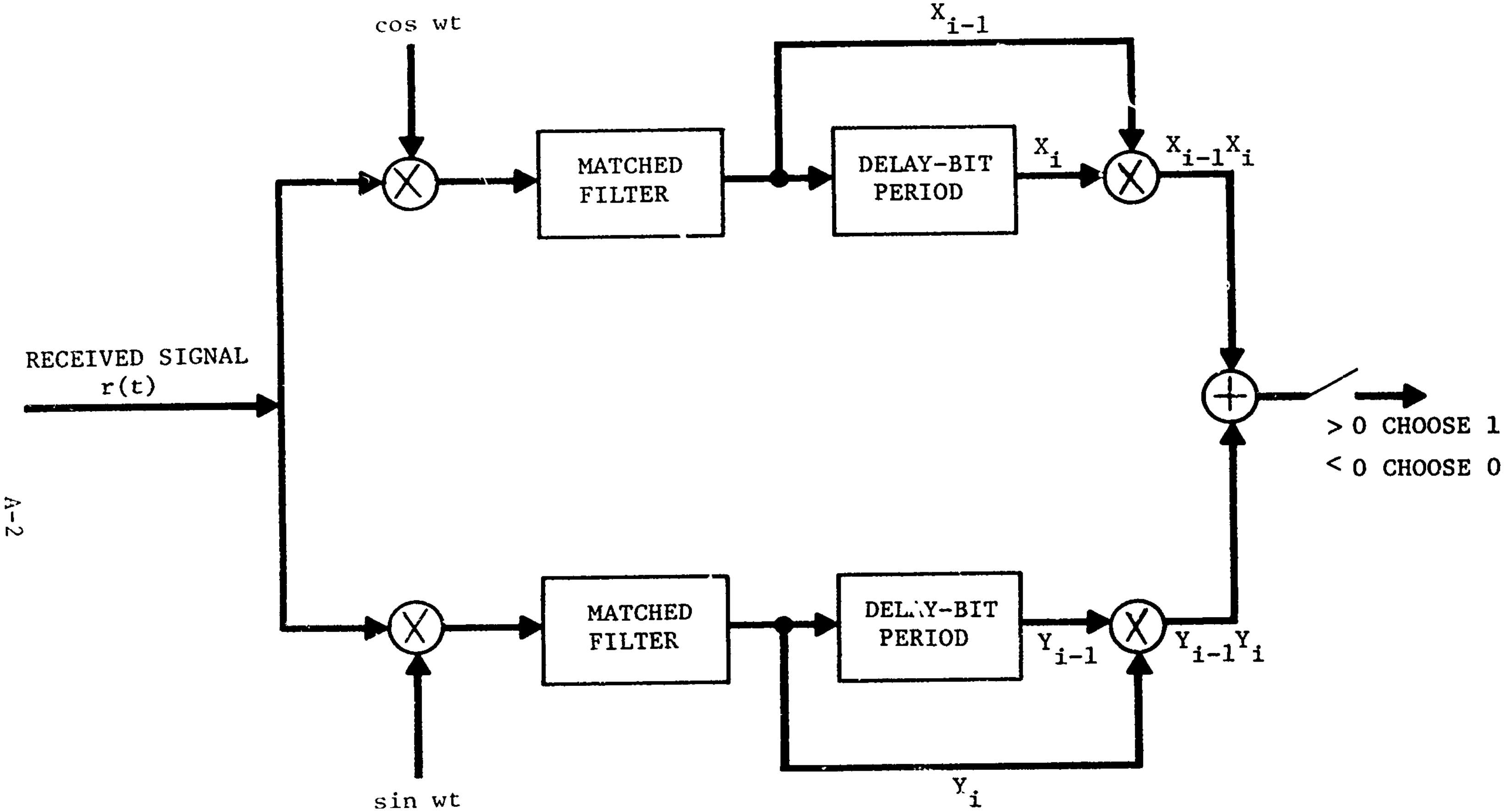

FIGURE A-1
BLOCK DIAGRAM OF DATA DETECTOR

$$\Lambda = X_{i-1}X_i + Y_{i-1}Y_i = \frac{1}{4}\left\{(X_{i-1} + X_i)^2 - (X_{i-1} - X_i)^2 + (Y_{i-1} + Y_i)^2 - (Y_{i-1} - Y_i)^2\right\} \tag{A-9}$$

Conditioned on θ, ϕ, and $P_{s\,i}$ for all i, Λ can be shown to represent the difference of two non-central chi-square random variables, each with two degrees of freedom. For data detection, what must be determined is the probability that Λ is greater or less than zero, conditioned on the above and depending on the ASTRO-DABS* data. The result is then averaged over the distributions of the remaining random variables. This is a non-standard calculation and, therefore, additional effort is required.

*A similar formulation is followed for the timing error variance calculation; however, the underlying chi-square distribution need not be employed.

$$\Lambda = X_{i-1}X_i + Y_{i-1}Y_i = \frac{1}{4}\Big\{(X_{i-1} + X_i)^2 - (X_{i-1} - X_i)^2$$

$$+ (Y_{i-1} + Y_i)^2 - (Y_{i-1} - Y_i)^2\Big\} \qquad \text{(A-9)}$$

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